LESSON 8

TOPIC 1

Deep Foundation Design – Load Capacity

Structural Foundation Topics

- ***Shallow Foundations (Spread Footings)***
  - ***Bearing Capacity***
  - ***Settlement***
- ***Deep Foundations***
  - ***Load Capacity***
  - ***Settlement***
  - ***Negative Skin Friction***

Slide 8-1-1

DEEP FOUNDATION DESIGN

Lesson 8 - Topic 1
Load Capacity

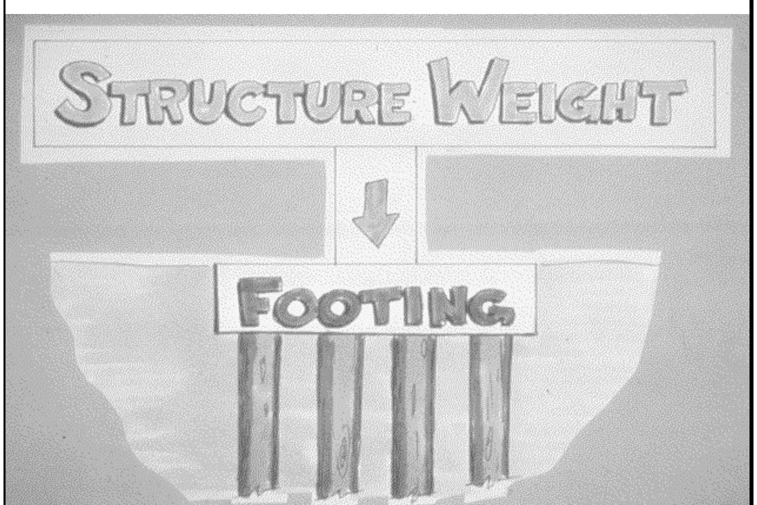
Slide 8-1-2

DEEP FOUNDATION DESIGN
Load Capacity

1. Describe Properties of the Pile and the Ground Which Affect Bearing Capacity

ACTIVITY: ***Static Analysis & Interpretation***

Slide 8-1-3



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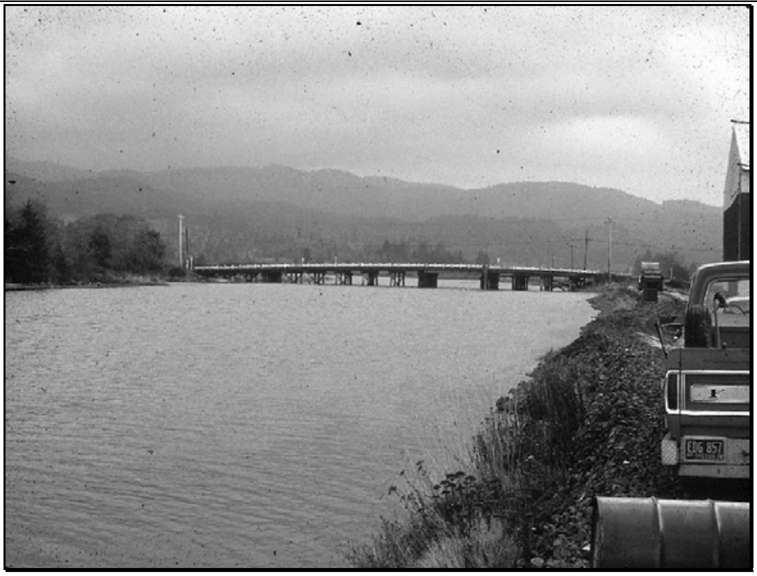

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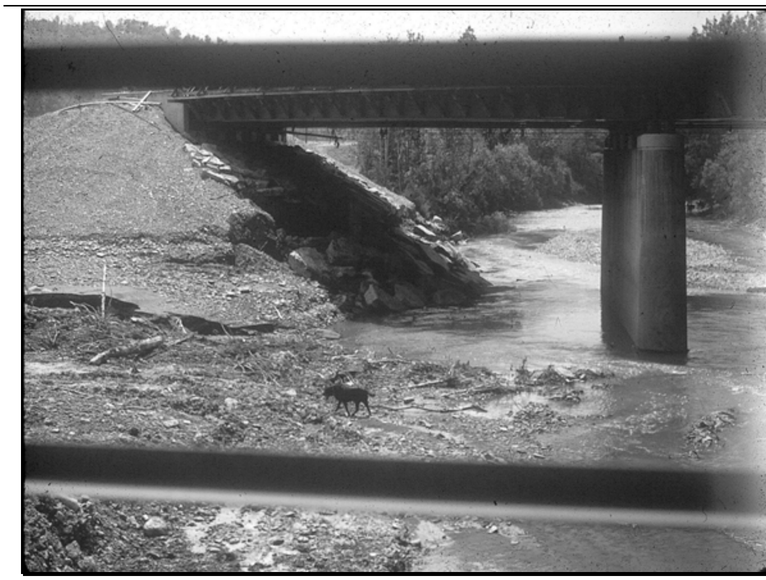

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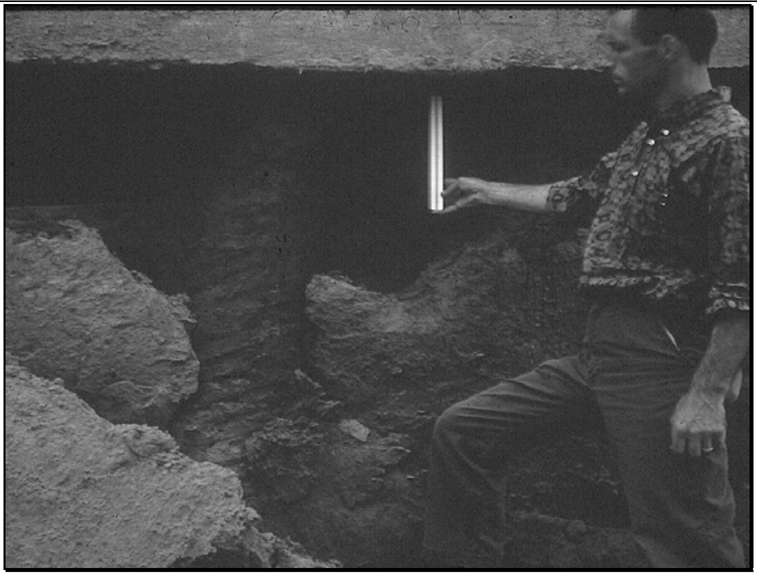

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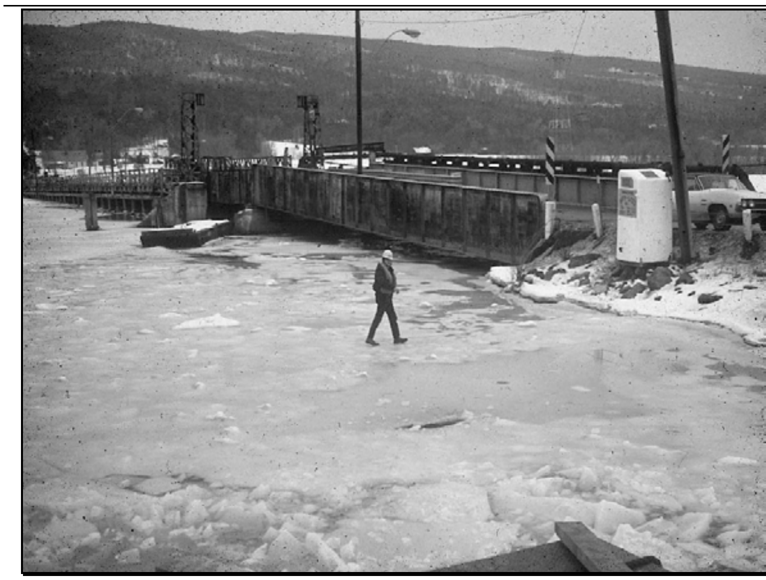

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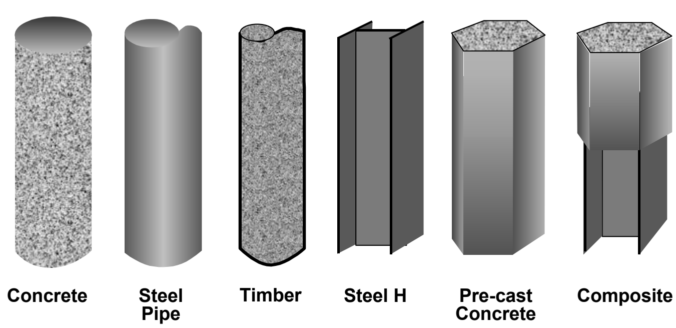
Types of Piling



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Individual Piles

Method of Estimating Load Capacity

- ***Load Test***
- ***Dynamic Formula***
- ***Static Analysis***

Slide 8-1-11

Slide 8-1-12

Slide 8-1-13

Steps in Rational Pile Selection

- ***Adequate Subsurface Investigation***
- ***Soil Profile Development***
- ***Appropriate Lab/Field Testing***
- ***Selection of Soil Design Parameters***
- ***Static Analysis***
- ***Applied Experience***

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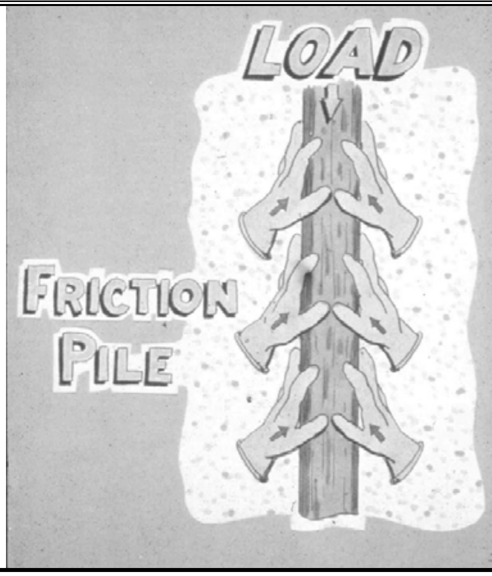

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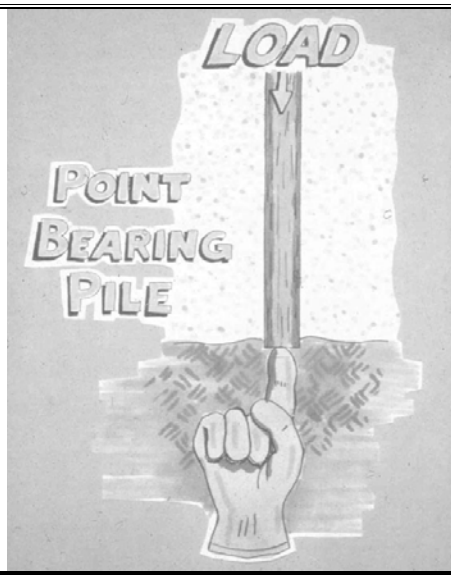

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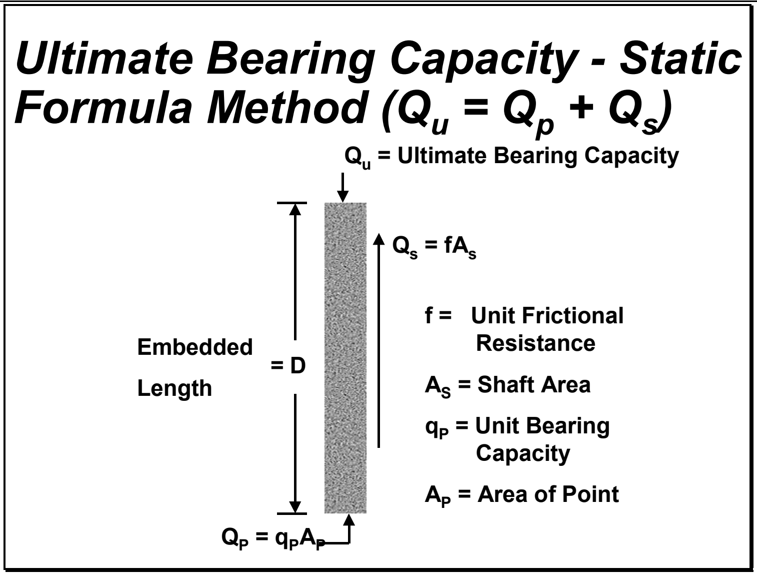

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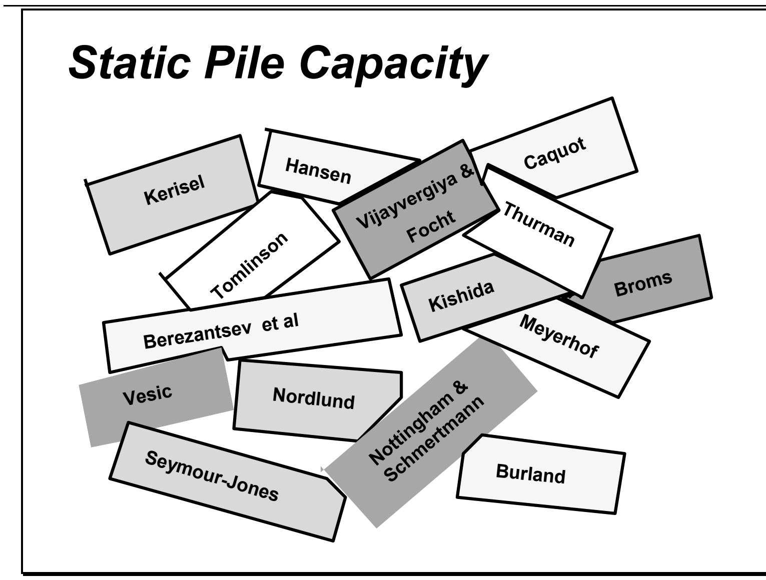

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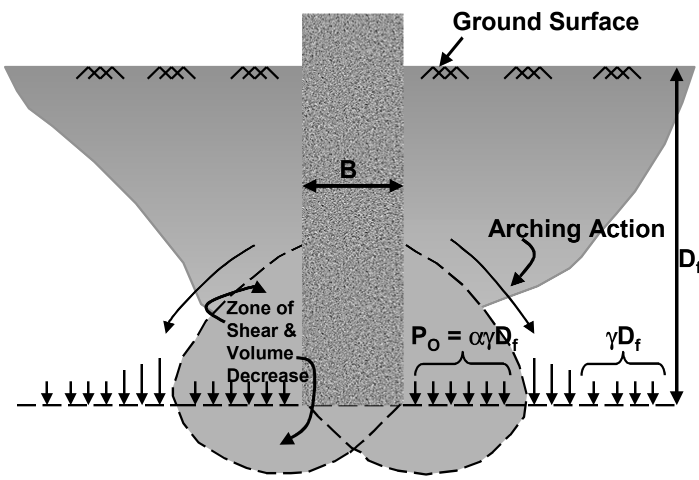
ALLOWABLE LOAD ON PILES IN COHESIONLESS SOILS

- ***General failure mechanism understood***
- ***Some uncertainty in effects of pile installation on load transfer in both skin friction and end bearing***

Slide 8-1-19

Arching at Pile Tip



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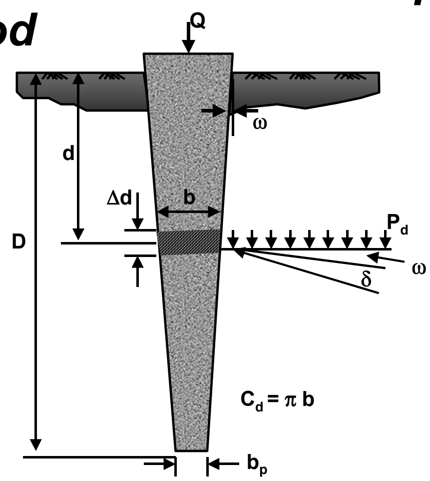
Nordlund's Static Pile Capacity Method



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Ultimate Capacity of Non-Tapered Piles in Granular Soils

$Q_u = Q_S + Q_P$

$Q_u = K_\delta C_F P_d \sin\delta \; C_d D + A_P \alpha P_D N'_q$

Unknowns are K_δ, C_F, δ, α, N'_q

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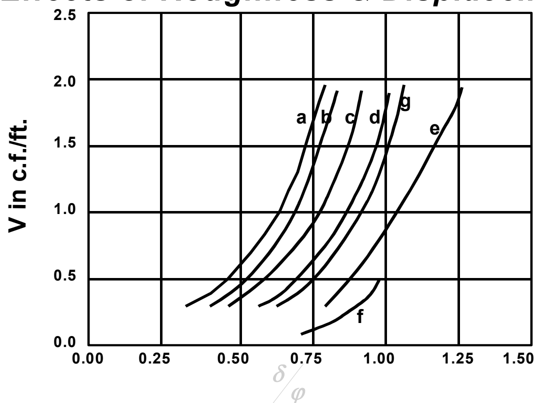
Skin Friction in Granular Soils
- Effects of Roughness & Displacement



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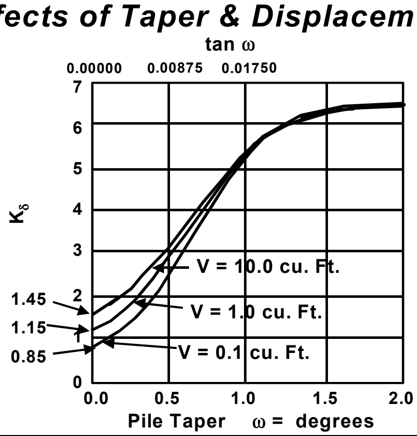
Skin Friction in Granular Soils
- Effects of Taper & Displacement



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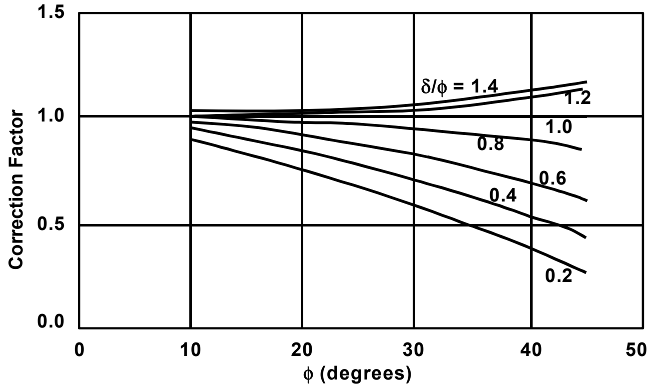
Skin Friction in Granular Soils Correction Factor if $\delta \neq \phi$



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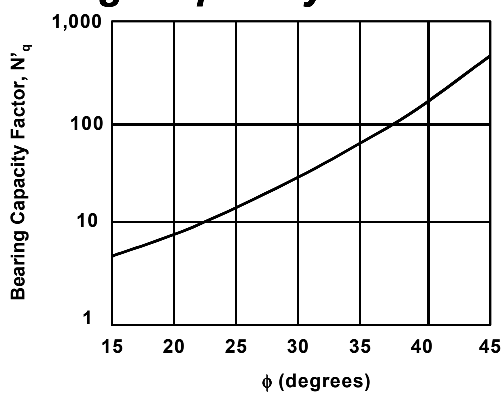
End Bearing in Granular Soils Bearing Capacity Factor - N'_q



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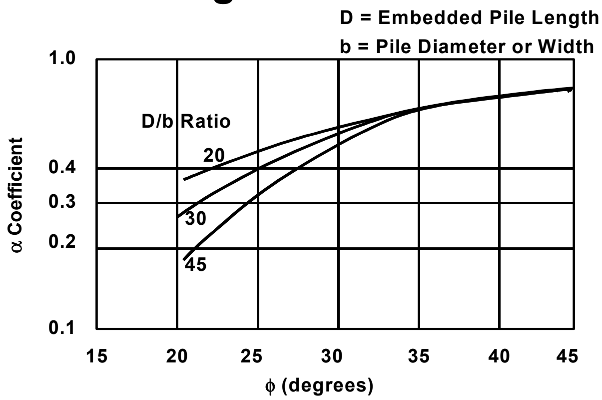
End Bearing in Granular Soils Soil Arching Effects - α



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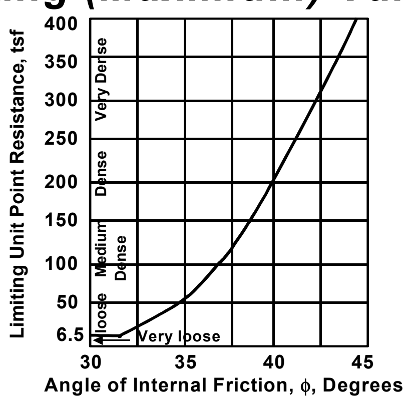
End Bearing in Granular Soils Limiting (Maximum) Value



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Slide 8-1-30

Slide 8-1-31

SOILS AND FOUNDATIONS WORKSHOP

Static Analysis Equation (Granular Soil)

$$Q_s = K_\delta C_F P_d \; \text{Sin}\,\delta \quad C_d\, D$$

(Normal Force) (Tangent φ) (Pile Surface Area)

$$Q_p = A_p \quad \alpha P_D \quad N'_q$$

(Point Area) (Reduced P_o) (Bearing Capacity Factor)

Slide 8-1-32

SOILS AND FOUNDATIONS WORKSHOP

Skin Friction Computations

- ***Compute volume per unit length***
- ***Enter Figure 8-1 with volume and pile type to find δ/ϕ. Then compute δ (interface friction angle)***
- ***Enter Figures 8-2 to 8-5 to find the lateral earth pressure coefficient, K_δ for the given value of ϕ and unit volume***

Slide 8-1-33

SOILS AND FOUNDATIONS WORKSHOP

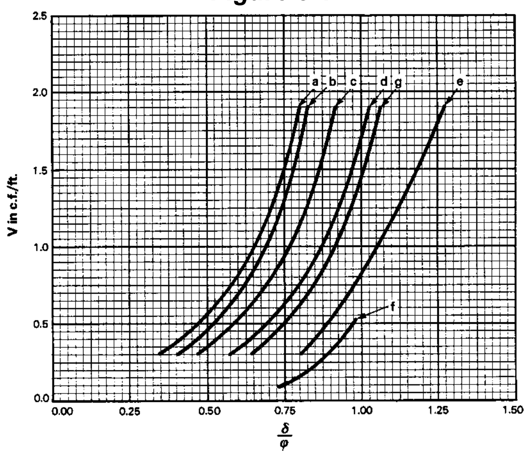
Skin Friction Computation (Cont'd)

- ***Enter Figure 8-6 with ϕ and the value of δ/ϕ to find the correction factor C_F for K_δ***
- ***Use P_o average and pile geometry to compute skin friction***

Slide 8-1-34

SOILS AND FOUNDATIONS WORKSHOP

Figure 8-1

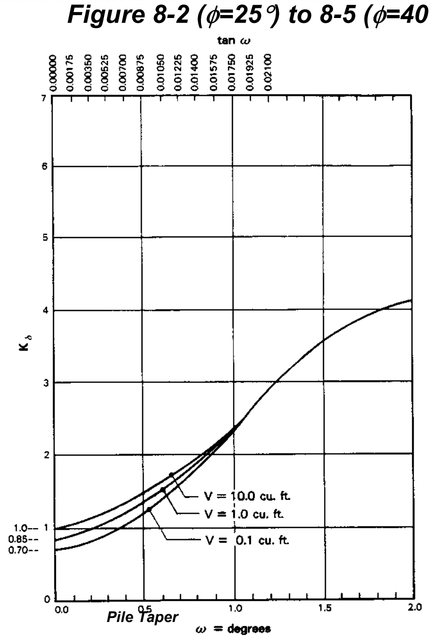


a. Pipe piles and non-tapered portion of monotube piles
b. Timber piles
c. Precast concrete piles
d. Raymond step-taper Piles
e. Raymond uniform taper piles
f. H-piles
g. Tapered portion of monotube piles

Slide 8-1-35

SOILS AND FOUNDATIONS WORKSHOP

Figure 8-2 (ϕ=25°) to 8-5 (ϕ=40°)



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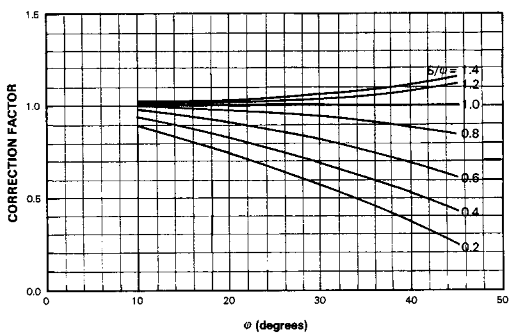
SOILS AND FOUNDATIONS WORKSHOP

Figure 8-6



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SOILS AND FOUNDATIONS WORKSHOP

End Bearing Rules Granular Soils

- ***P_D should not exceed 3000 psf for end bearing computations***
- ***Q_p must be compared to the limiting maximum end bearing for the soil friction angle selected.***

Slide 8-1-38

SOILS AND FOUNDATIONS WORKSHOP

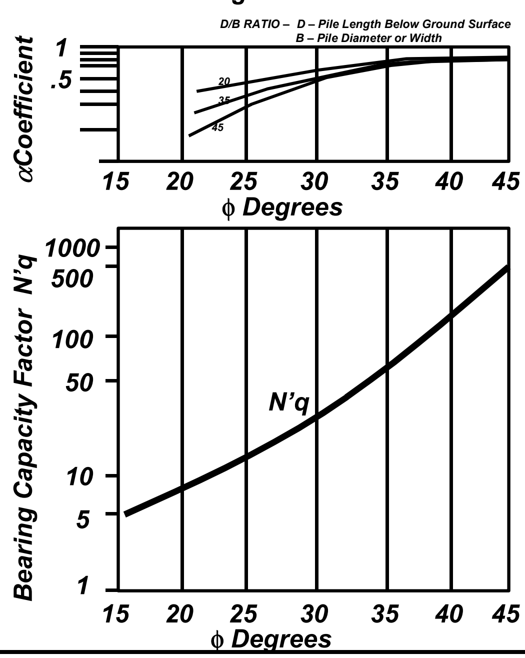
End Bearing Rules Granular Soils (Cont'd)

- ***Q_{LIM} = (Unit Point Resistance from figure 8-7B)(Pile End Area)***
- ***The lesser of Q_{LIM} or Q_p is used as the end bearing value***

Slide 8-1-39

SOILS AND FOUNDATIONS WORKSHOP

Figure 8-7a



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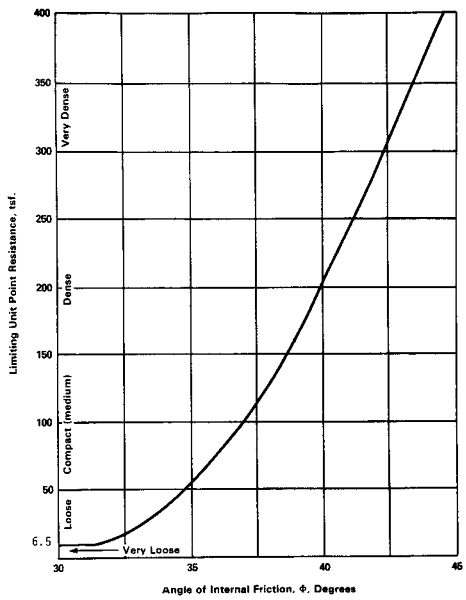
SOILS AND FOUNDATIONS WORKSHOP

Figure 8-7b



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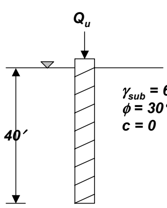
SOILS AND FOUNDATIONS WORKSHOP



γ_{sub} = 62.5 pcf
ϕ = 30°
c = 0

$Q_u = A_p\, \alpha\, P_D\, N'_q + K_\delta\, C_F\, P_d\, \text{Sin}\,(\delta + \omega)\, C_d\, D$

Where the following terms are known from the problem

A_p = 1 sq.ft
$P_D = 40\ \gamma_{sub}$ = 2500 psf
$P_d = 20\ \gamma_{sub}$ = 1250 psf
ω = 0°, D = 40′, C_d = 4′

Solution:

Find Point Resistance, Q_P:

Use Figure 8-7A to Find N'_q and α for ϕ = 30°

$N'_q = 30$ $\qquad \alpha = 0.5$ (for $\frac{D}{B} = 40$)

$Q_p = A_p \alpha P_D N'_q$

= (1 sq.ft)(0.5)(2500 psf) 30 = 18.75 tons

Check Limiting Point Resistance from Figure 8-7B

$Q_{Lim} = Q_{Lim}\, A_p$ = (6.5 tsf)(1 sq.ft) = 6.5 tons

$\therefore Q_p$ = 6.5 tons

Slide 8-1-42

SOILS AND FOUNDATIONS WORKSHOP

Find Skin Resistance, Q_S:
Use Figures 8-1, 8-3, and 8-6 with ϕ = 30°

Figure 8-1 – For V = 1 cubic ft. per ft., and curve "C" for precast concrete piles;

$\frac{\delta}{\phi} = 0.76$, Since $\phi = 30°$, $\delta = 22.8°$

Fig. 8-3 – For ω = 0, V = 1 cu.ft/ft ;

$K_\delta = 1.15$

Fig. 8-6 – For $\frac{\delta}{\phi} = 0.76$;
$C_F = 0.9$

$Q_s = K_\delta C_F P_d \sin \delta C_d D$

$Q_s = (1.15)(0.9)(1250 \text{ psf})(\sin 22.8)(4') 40'$
<u>$Q_s = 40.1$ tons</u>

<u>$Q_u = 6.5 + 40.1 = 46.6$ tons</u>

Slide 8-1-43

ALLOWABLE LOAD ON PILES IN COHESIVE SOILS

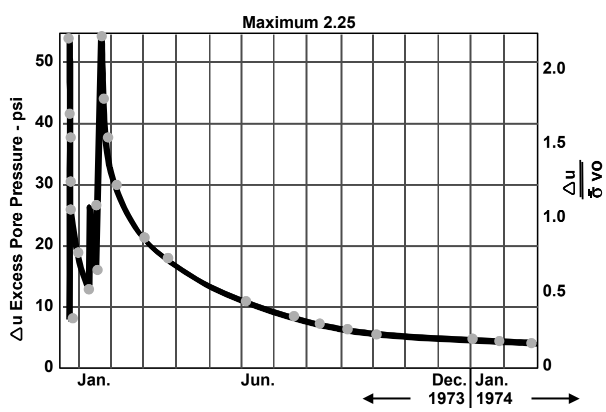
- *General failure mechanism well understood*
- *Pile capacity immediately after driving is affected by excess pore pressures*
- *Long term pile capacity is based on reconsolidated soil strength*

Slide 8-1-44

Slide 8-1-45

Pore Pressure – South Bay Bridge

Pier No. 3, Piezometer Nos. 1 & 2



Slide 8-1-46

Ultimate Capacity of Piles in Cohesive Soils

$$Q_{ult} = C_a\, C_d\, D + 9\, C_u\, A_P$$

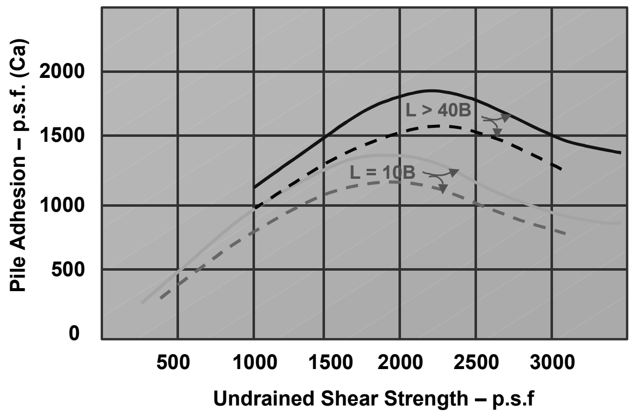
Slide 8-1-47

Adhesion on Piles in Saturated Clay (Circa 1960)

Material	*Cohesion (psf)*	*Adhesion (psf)*
Concrete and Timber	*Soft 0 – 750* *Firm 750 – 1500* *Stiff 1500 - 3000*	*Soft 0 – 750* *Firm 750 – 1250* *Stiff 1250 – 1400*
Steel	*Soft 0 – 750* *Firm 750 – 1500* *Stiff 1500 – 3000*	*Soft 0 – 600* *Firm 600 – 1050* *Stiff 1050 – 1200*

Slide 8-1-48

Effect of Pile Embedment on Adhesion in Cohesive Soils



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SOILS AND FOUNDATIONS WORKSHOP

Static Analysis Equation Cohesive Soils

$$Q_{ULT} = C_a \quad C_d\,D \quad + \; 9\,C_u \quad A_p$$

(Adhesion) (Pile Surface Area)+ (Shear Strength)(Point Area)

*** Remember end bearing mobilization requires a pile tip movement of about 10% of pile diameter*

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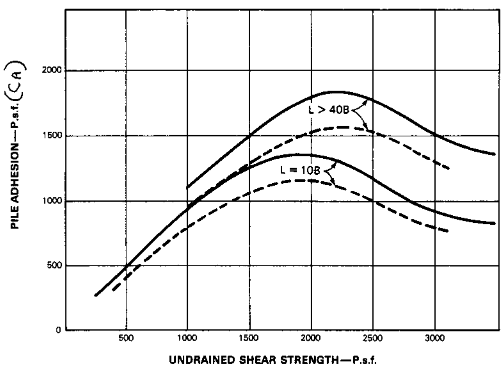
SOILS AND FOUNDATIONS WORKSHOP

Figure 8-8

Adhesion values for piles in cohesive soils



Legend: L = Distance from ground surface to bottom of clay layer or pile tip; whichever is less
B = Pile diameter

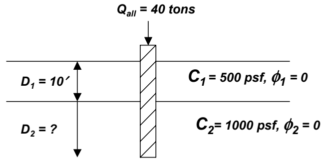
——— Concrete, timber, corrugated steel piles
— — – Smooth steel piles

Reference: Based on Tomlinson 1979

Slide 8-1-51

SOILS AND FOUNDATIONS WORKSHOP

Example: Determine the Required Pile Length To Resist A 40 Ton Load with A Safety Factor Of 2. Assume No Point Capacity For the 1′ Square Precast Concrete Pile.



Solution:

$Q_u = C_{a1}\, C_{d1}\, D_1 + C_{a2}\, C_{d2}\, D_2$

$C_{d1} = C_{d2} = 4 \times 1' = 4'$

From Figure 8-8, find C_a for a rough pile

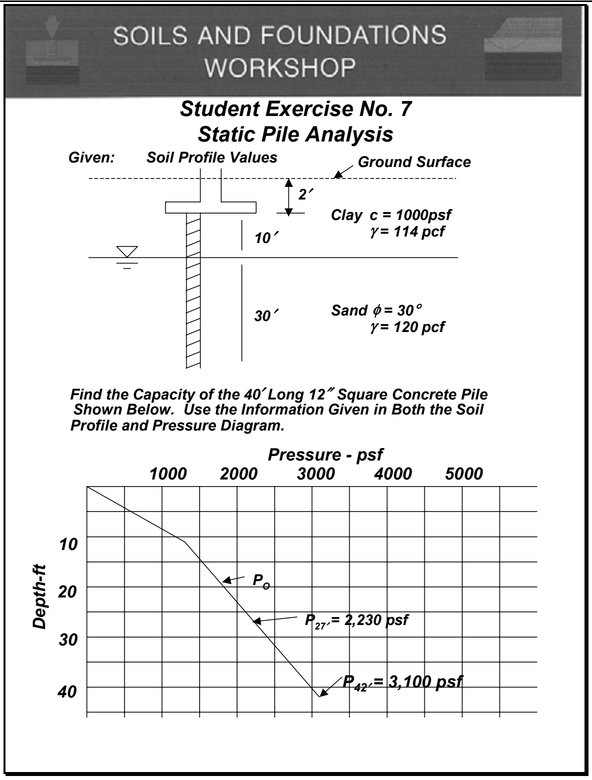
C_{a1} = 500 psf (L=10B)
C_{a2} = 1100 psf (Assume L > 40B)

Q_u = 40 tons $\times$ 2 = 80 tons = (500 psf)(4′)(10′) + (1100 psf)(4′)D_2

$$D_2 = \frac{80 - 10}{2.2} = 32'$$

$\therefore$ *Total pile length required = 32′ + 10′ = 42′*

Slide 8-1-52



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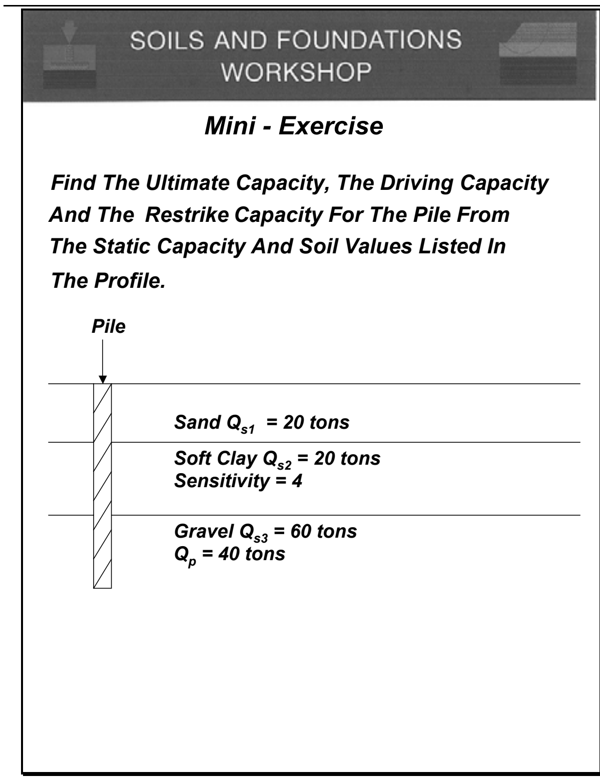

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SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY

Site Exploration

Basic Soil Properties

Laboratory Testing

Slope Stability

Embankment Settlement

Spread Footing Design

PILE DESIGN

- *Static Analysis – Pier*
  - *Pipe Pile*
  - *H – Pile*
- *Abutment*
  - *Pipe Pile*
  - *H – Pile*
- *Driving Resistance*
- *Abutment Lateral Movement*

Construction Aspects

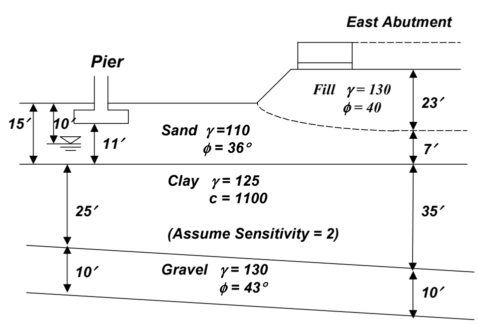
Slide 8-1-55

SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY

PILE FOUNDATION DESIGN

ASSUME SOIL PROFILE VALUES BELOW



- *Pile Minimum Depth*
- *Pile Material*
- *Pile Shape*
- *Driving Resistance*
- *Pre-augering for Abutment Piles*
- *Other issues?*

Slide 8-1-56

SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY
PILE DESIGN

Design Soil Profile

Strength value selected for all layers.

Static Analysis - Pier

12" - 70 T Pipe Pile - 36' length required
12" - 120 T H-Pile - 46' length required.

Static Analysis Abutment

12" - 70 T Pipe Pile - 65' length required
12" - 120 T H-Pile - 75' length required.

Driving Resistance

Driving Resistances computed for both pipe (max 216 T) and H-piles (max 345 T) to permit design check of pile section overstress.

Pipe pile will require pre-augering through embankment.

Slide 8-1-57

SOILS AND FOUNDATIONS WORKSHOP

Deep Foundation Design - Load Capacity

- ***Describe the properties of the pile and the ground which affect bearing capacity***

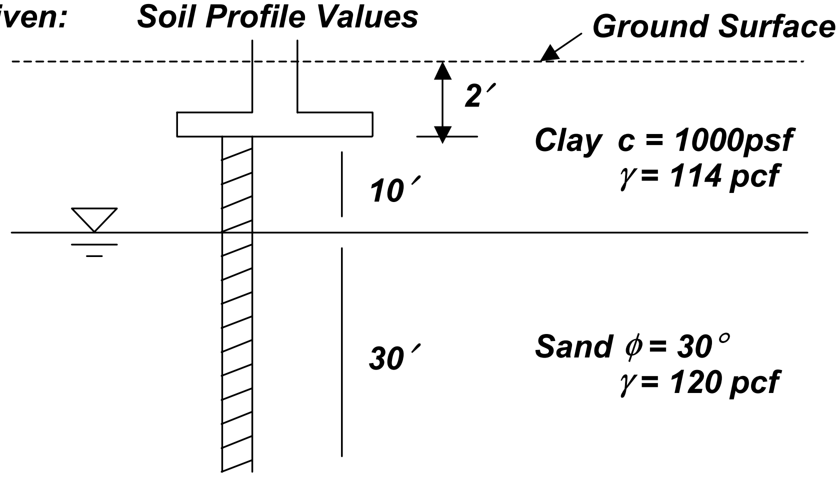
Activities: Static analysis computation and interpretation of results

Slide 8-1-58

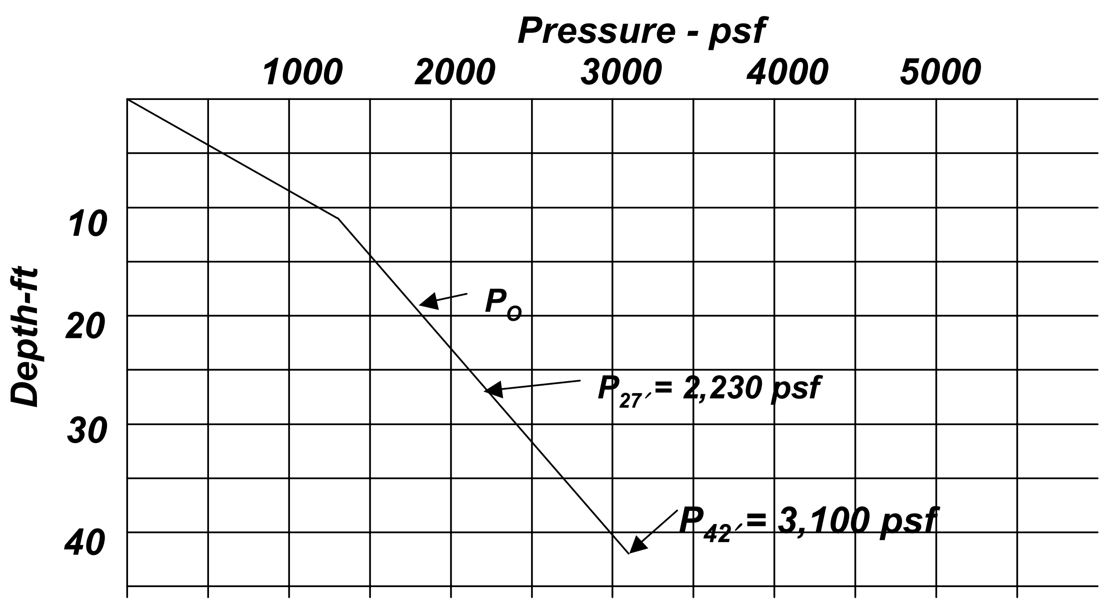
SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 7
Static Pile Analysis

Given: Soil Profile Values



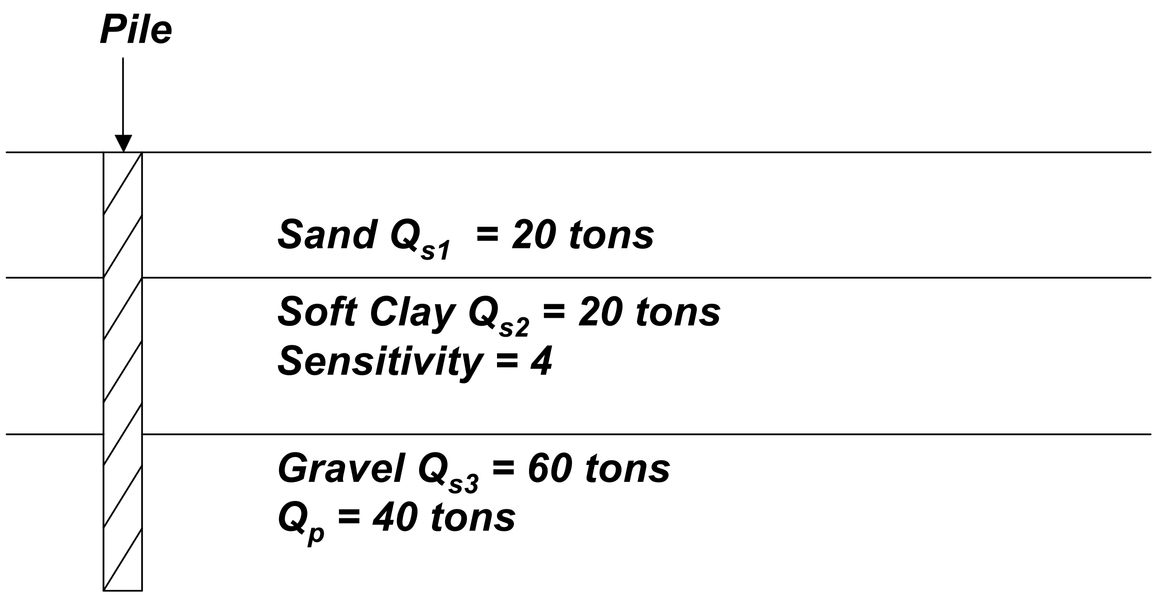
Find the Capacity of the 40′ Long 12″ Square Concrete Pile Shown Below. Use the Information Given in Both the Soil Profile and Pressure Diagram.



SOILS AND FOUNDATIONS WORKSHOP

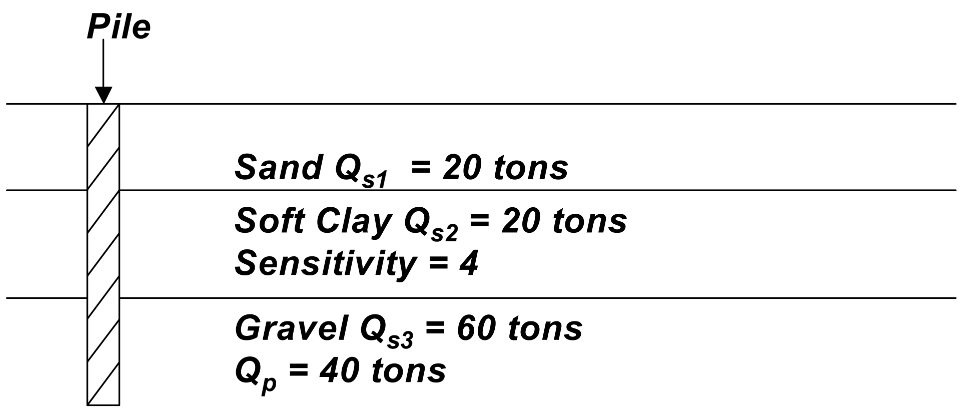
Mini - Exercise

Find The Ultimate Capacity, The Driving Capacity And The Restrike Capacity For The Pile From The Static Capacity And Soil Values Listed In The Profile.



SOILS AND FOUNDATIONS WORKSHOP

Mini – Exercise Solution



Ultimate capacity $= Q_{s3} + Q_P = 60 + 40 = 100$ ***tons***

Driving capacity $= Q_{s1} + (Q_{s2} \text{Sensitivity}) + Q_{s3} + Q_P$

$$= 20 + \frac{20}{4} + 60 + 40 = 125 \text{ tons}$$

Restrike capacity $= Q_{s1} + Q_{s2} + Q_{s3} + Q_P$

$$= 20 + 20 + 60 + 40 = 140 \text{ tons}$$